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THE LOGARITHMIC NATURE OF THERMAL DEATH TIME CURVES

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In the article by Bigelow and Esty,[1] the term "thermal death point in relation to time" was used to designate the time necessary to destroy bacterial spores at a specified temperature, the kind of medium and its hydrogen-ion concentration also being given. In this article the term "thermal death time" is used to express the same idea.

In fig. 1 of the article mentioned is shown a series of curves on coordinate paper representing the thermal death times of the spores of various thermophilic bacteria at intervals of 5 C. On the opposite page are given the detailed data from which the curves were constructed. It is noted in the same article that since the curves on fig. 1 are approximately parallel, it is necessary to determine only the time required to destroy a given number of spores of an organism of this class at a given temperature in order to construct the entire curve.

The writer has since plotted the same curves on semilog paper, and the resulting straight line curves show in a much more striking manner than do the curves on coordinate paper the relations to each other of the thermal death times at different temperatures.

In table 1 of the article mentioned are shown the longest time each organism survived and the shortest time in which all spores were killed at each of several temperatures.

In chart 1 of the present article the last positive and first negative results of 6 organisms taken from the table referred to are entered on semilog paper, and the points of observation for each organism at different temperatures are connected by a straight line. Numbering the curves from left to right, the time which the organisms survived is indicated by a plus sign on the first, third and fifth curves and the shortest time required to kill them by a circle. On the second, fourth and sixth curves these times are represented, respectively, by a cross and a dot. The 6 curves represent the results from 6 typical organisms taken from the table referred to. In this way it is made clear to which curve the various observation points belong. The curves are

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[1] Jour. Infec. Dis., 1920, 27, p. 602.

so drawn as to pass between the last positive and first negative in the greatest possible number of pairs of observation points with each organism. There are 30 pairs of observation points (last positive and first negative in each case) with the 6 organisms shown in chart 1.

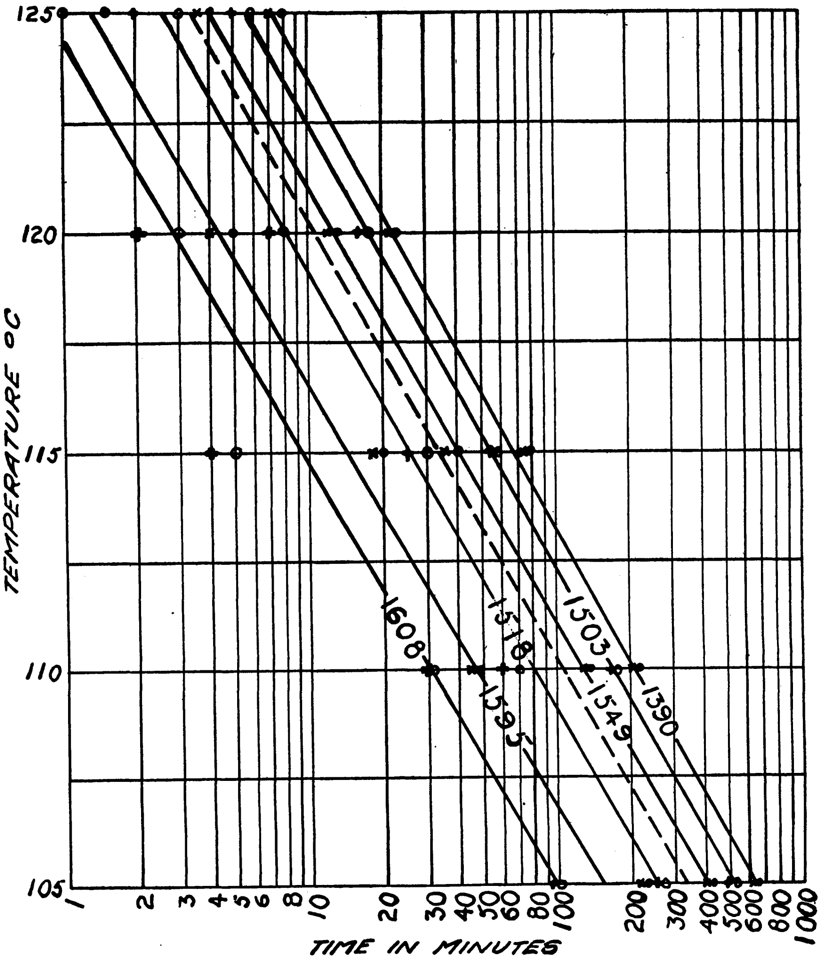

Chart 1.—Thermal death time curves.

Between 105 and 125 C. inclusive, it will be noted that the thermal death time curves pass through all but 6 of these 30 pairs of observation points. The average of the 6 curves is given as a line of bars. The data given in the table mentioned were also plotted on semilog paper for the other 9 organisms with resulting straight thermal death time curves approximately parallel to each other and also to those shown in chart 1. These 9 curves were omitted from chart 1 in order to avoid confusion.

The similarity of these curves to one another suggested the advisability of drawing a curve which would represent the average of all 15. This would be almost parallel with each of the 15 and would serve to obliterate small errors of the individuals. The data for this curve were secured by averaging separately all of the columns in the table referred to in the foregoing. These average figures are given in table 1.

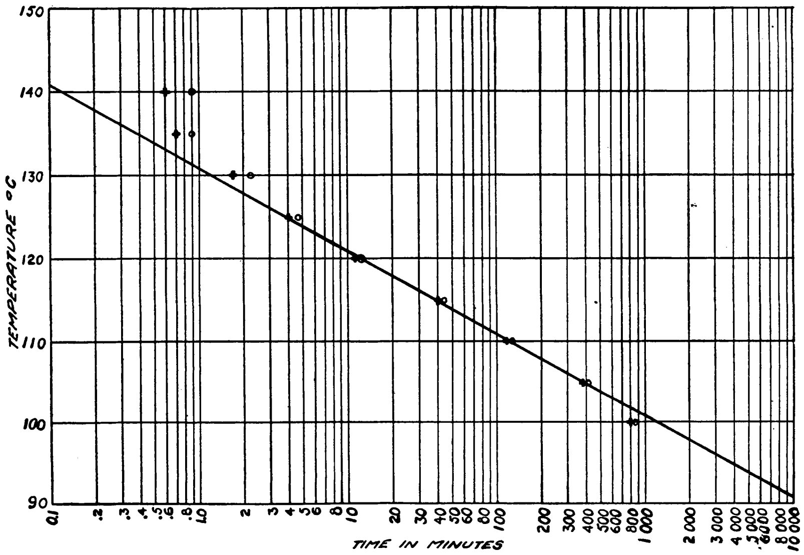

Chart 2.—Average thermal death time curve.

TABLE 1

Average Thermal Death Time of 15 Typical Thermophiles at Temperatures Stated

Temperature *Degrees C.*	Last Plus Reading *Minutes*	First Minus Reading *Minutes*
100	788	834
105	383	405
110	117	122
115	40	44
120	11	12
125	39	46
130	1.7	2.2
135	0.7	0.9
140	0.6	0.9

The data shown in this table are arranged on semilog paper in chart 2, the last positive result being represented by a plus and the first negative result by a circle.

It will be noted that the curve is a straight line and passes between all positive and negative observation points from 105 to 125 C. inclusive. Between these temperatures, therefore, the thermal death time curves of these 15 typical thermophilic bacteria are logarithmic curves and can obviously be drawn more accurately on semilog paper than on coordinate paper.

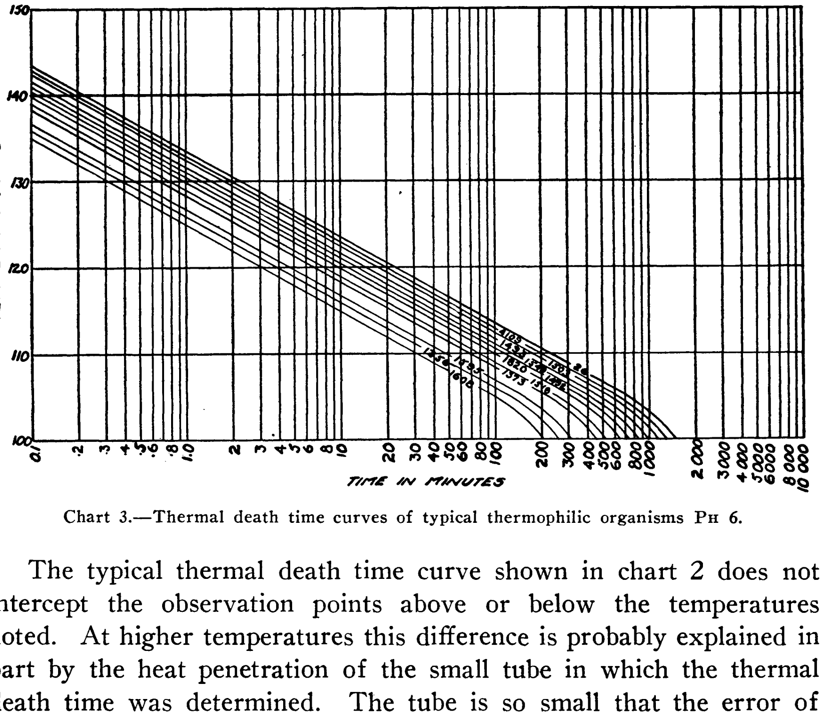

Chart 3.—Thermal death time curves of typical thermophilic organisms PH 6.

The typical thermal death time curve shown in chart 2 does not intercept the observation points above or below the temperatures noted. At higher temperatures this difference is probably explained in part by the heat penetration of the small tube in which the thermal death time was determined. The tube is so small that the error of heat penetration is not great, but the time required to destroy the spores at temperatures above 125 C. is so short that the retarding influence of heat penetration is doubtless partly responsible for the deflection of the observation points from a straight line.

In chart 3 the thermal death time curves on semilog paper are given for 12 of the 15 organisms in question. The curves for the other three organisms would have practically coincided with three of those shown. These are drawn in such a way as to coincide as nearly as possible with the observation points of each organism between the temperatures of 105 and 125 C., but care is taken to make the lines all parallel to the average curve shown in chart 2. Below 105 C. the lines are drawn parallel (measured horizontally) to each other and are curved so that they intercept the proper point on the 100 degree line. This was accomplished by drawing the average curve shown in chart 2 so that it curved between 100 and 105 C. and intercepted the 100 degree line between the plus and minus readings, giving the individual lines in chart 3 the same curvature.

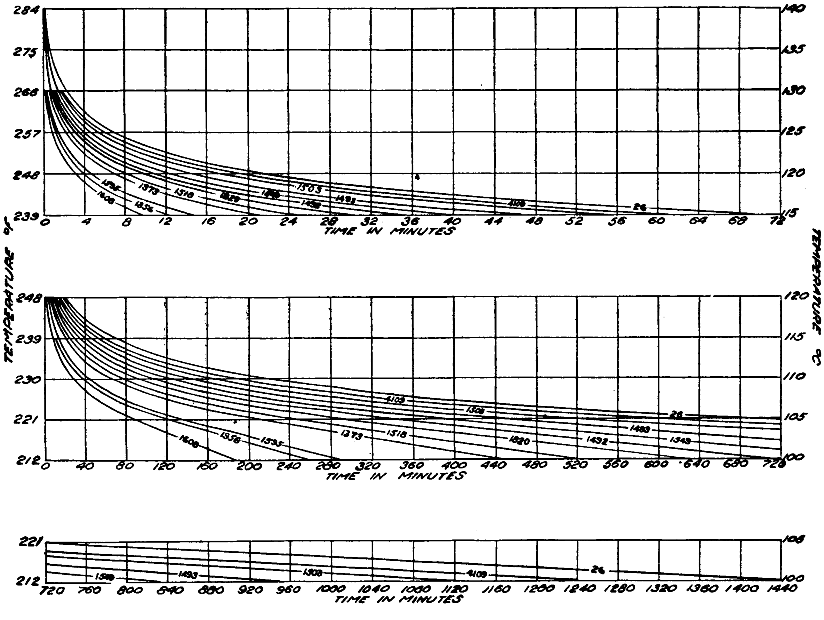

Chart 4.—Thermal death time curves of typical thermophilic organisms Pʜ 6.

Above 125 C. the curves are extended to the end of the cut as a matter of convenience. It is recognized that they are inaccurate at these high temperatures, possibly owing in part to the time required for the heat to penetrate to the center of the tubes. This, however, cannot be the only factor concerned. The lower three of the 12 organisms shown in chart 3 required less than 2 minutes for their destruction at 125 C. and yet the curves coincide very well with the points of observation. On the other hand, the two most resistant organisms required 2 minutes for their destruction at 130 C. and the time indicated by the curves in chart 3 is noticeably less than the observed time.

The 15 organisms under discussion resemble each other in some respects but exhibit many dissimilarities. All are facultative anaerobes and none are gas-formers. The majority of them produce acid. One of them produces a bitter substance which has not been identified and another secretes an enxyme which hydrolizes starch to maltose. There are other marked points of dissimilarity which will be discussed by the associates of the writer in subsequent papers. Their dissimilarity is merely mentioned here as that fact considered in connection with the parallelism of the thermal death time curves suggests a general law which may be of value from a biologic standpoint and which is a great convenience in thermal death time work.

Since the curves are straight parallel lines when drawn on semilog paper, a type curve having the proper slope may be drawn on a blank sheet of the paper, as shown in chart 2. The time necessary to destroy a certain number of spores of a given bacterium may be determined and the last positive and first negative results entered in their appropriate positions on the same paper. Lines drawn through these points parallel to the type curve fix quite definitely the thermal death time curve of the organism between the temperatures of 105 and 125 C. These lines may be confirmed at other temperatures much more readily than by any other procedure, and a much smaller number of observations is required to draw an accurate curve than would otherwise be necessary.

It becomes a matter of interest to determine how generally this method of procedure may be applied to thermal death time work. The change in the direction of the curve below 105 C. suggests the possibility that the deflection may be due to some biologic change in the spores resulting from a closer approach to the temperatures at which they will germinate and the vegetative cells will grow. The maximum temperature of growth of the spores in question has not been determined in all cases but in some cases it is above 75 C. It would be interesting to extend these curves down to the maximum temperature of growth of the bacteria, but that procedure is rendered extremely difficult by the long time that would be required to destroy the spores at the lower temperatures.

The thermal death time curves shown in chart 3 are also shown in chart 4 on coordinate paper. In general, the latter do not differ greatly from the same curves shown in the article by Bigelow and

Esty,[1] although there is considerable difference in detail, especially at the lower temperatures. The advantage of using the straight line in connection with semilog paper and the advantage which semilog paper affords of comparing with other organisms suggests in the writer's opinion that where differences occur the curves, as shown in chart 4, are more representative of the thermal death time of the organisms than those shown in the article referred to.

It is of interest to note also whether the method of procedure described in the foregoing is applicable to nonspore-bearing bacteria.

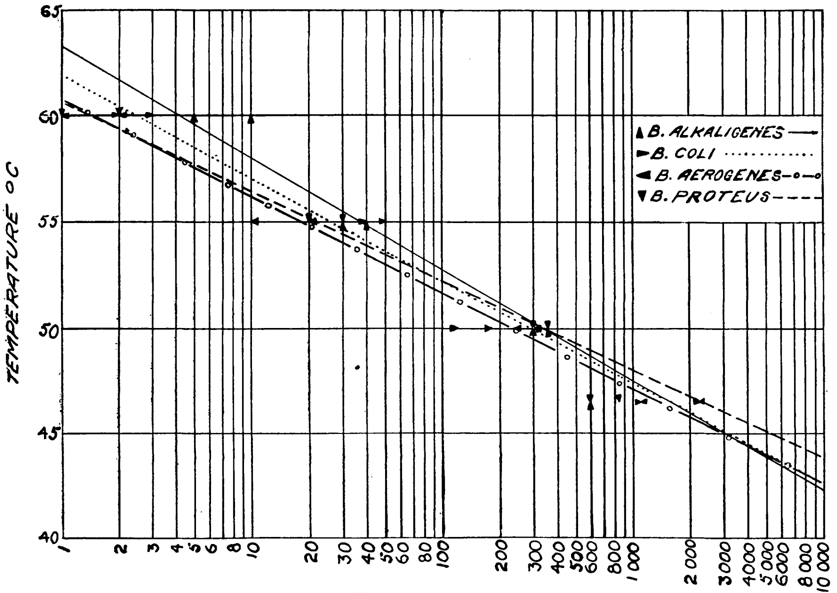

Chart 5.—Thermal death time curves of four non-spore-bearing organisms.

Unfortunately, work of this kind has not been carefully controlled and the literature does not appear to afford enough observation points to permit the plotting of the data recorded.

Four strains of nonspore-bearing bacteria were obtained through the kindness of Mr. L. A. Rogers, and their thermal death times were determined by the method described in the paper mentioned. The results are given in chart 5.

The points of observation are indicated by solid triangles as shown in the legend on chart 5. It was impossible to differentiate between the last positive and first negative results for each organism because of the number of characters necessary to give the data. This can be done readily by inspection. The last positive and first negative results are given in all cases except for B. alkaligines at 46.5 C., at which temperature no positive result was obtained for that organism. The curves shown in chart 5 do not intercept the points of observation as closely as in the case of the thermophiles thus far studied. This may be due, in part, to lack of sufficient data. From the nature of the case it was impossible to operate at temperatures widely different from each other. If this could have been done, more accurate curves might have been obtained. The results are sufficiently consistent, however, to suggest that thermal death time curves of nonspore-bearing bacteria are logarithmic.

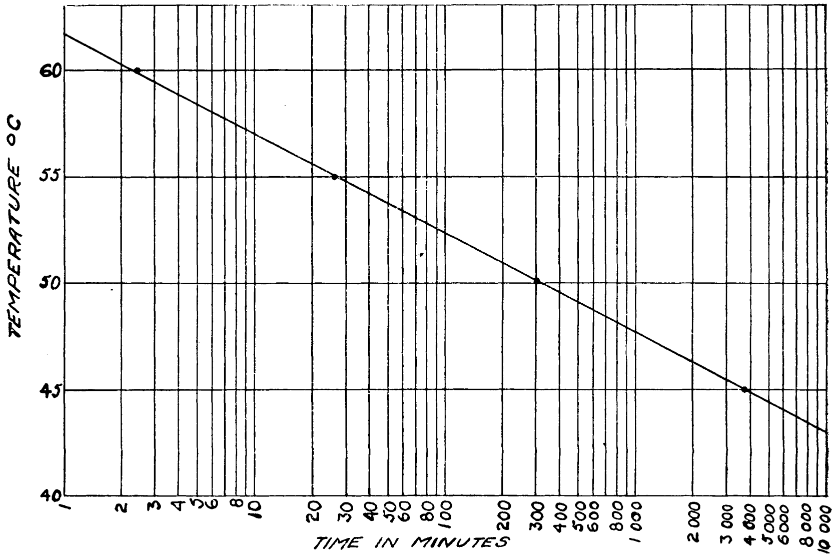

Chart 6.—Average thermal death time curve of four non-spore-bearing organisms.

These curves are not as nearly parallel as those of the various thermophilic spores, but they approach parallelism sufficiently closely to be convenient in thermal death time study and possibly to be of value in the study of other biologic relations in micro-organisms. The curves in question represent only a few determinations and should be confirmed before being definitely accepted. They are given here more to illustrate the general question of the nature of the curves than as a record of thermal death time.

The mathematical average of the four curves shown in chart 5 was calculated at four temperatures, and the results are indicated in chart 6 by dots connected by a straight line which is therefore the average curve of the four thermal death time curves shown in chart 5. It will be noted that the slope of this curve is only about one half that of the curves shown in charts 1 to 3 inclusive for thermophilic organisms. It is probable that this curve will coincide sufficiently closely in slope with the curves of many nonspore-bearing bacteria to make it of value as a guide in thermal death time work. It is hoped that other workers in this field will apply the method in order that the extent of its application may be determined. It is suggested that the thermal death time curve of nonspore-bearing bacteria which will not grow between the temperatures of 45 and 60 C. will probably be approximately parallel to the curve shown in chart 6; if not, the direction of the semilog thermal death time curves may afford an additional means of distinguishing species or classes of bacteria.

The foregoing data were secured by heating spores in juice expressed from canned corn with a p_H value of 6.1. Somewhat different curves are secured at other p_H values.